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DEVELOPMENT OF A SOIL TREATMENT MATERIAL TO SERVE AS A DUST PALLIATIVE IN THE THEATER OF OPERATIONS

FINAL REPORT

by

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October 1967

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Conducted for

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by

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FOREWORD

The work in this report was performed under Contract Number DA-22-079-eng-486, entitled "Development of a Resinous Dust Control System for Use in the Theater of Operations," dated 3 June 1966, between the U. S. Army Engineer Waterways Experiment Station and The Western Company of North America. This research was sponsored by the U. S. Army Materiel Command under Department of the Army project DA 1-V-0-21701-A-046, "Trafficability and Mobility Research," Task 05, "Mobility Engineering Support (Dust Control, Southeast Asia)."

This report was prepared by James B. Dobbs and Marie Hitchcock of the Chemistry Department of the Research Division of The Western Company. This program was under the general supervision of Dr. A. M. Spencer, head-Chemistry Department, and Dr. W. E. Brown, Manager-Research Division and Vice President of The Western Company.

The contract was monitored by Mr. G. R. Kozan, Chief, Stabilization Section, Expedient Surfaces Branch, under the general supervision of Mr. W. J. Turnbull, Chief, Soils Division, WES. Contracting officer was Col. J. R. Oswalt, Jr., CE.

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SUMMARY

This report describes the efforts to develop a soil stabilizing additive which would serve as an effective dust palliative in the theater of operations.

In the initial phase of the testing program a large number of soil treatment candidates were screened. To accomplish this, small specimens were prepared and observed. The most satisfactory of these candidates were evaluated by the WESSS-3 standard procedures designated "Tests for Screening of Proposed Dust-Control Materials".

Two candidates were selected on the basis of their good performance for small scale pilot tests. One square yard specimens were prepared over various types of uncompacted clay and sand and exposed to weathering. A single candidate was selected for further testing.

Full scale pilot plot tests were conducted with the fully developed product over compacted clay and loam under both summer and winter conditions. All specimens were then submitted to trafficability tests.

A soil treatment material has been recommended which is a terpolymer blend of polyvinyl acetate, polyvinyl acrylates and internal plasticizers.

DEVELOPMENT OF A SOIL TREATMENT MATERIAL TO SERVE AS A DUST PALLIATIVE IN THE THEATER OF OPERATIONS

PART I: INTRODUCTION

Purpose

The purpose of this program was to provide a soil stabilizing additive which would serve as an effective dust palliative in the theater of operations.

Scope

The work was conducted as an effort to alter slightly or change the properties of a product already in existence, so as to make it fit the requirements of a dust palliative. The goals were to take a product and apply it to the problem at hand with a minimum of research time and effort and to be able to supply said product on short notice.

The actual development of equipment and techniques for field use was beyond the scope of this program.

PART II: THE PROBLEM

In this age of "limited warfare," mobility has become the key consideration. The helicopter, VTOL, and STOL aircraft have rapidly become workhorses of the modern, mobile, tactical unit. Because of their unique capabilities they can rapidly transport troops or supplies to almost any locality. However, operations in certain areas can be severely curtailed due to local soil conditions. In some areas the soil must be stabilized in some manner before operations are feasible. In most areas, successive operation from the same location without soil stabilization or site preparation results in operational difficulties.

One of the greatest problems associated with the operation of helicopters or STOL aircraft from an unprepared site, or from unstabilized soils, is the dust cloud which is generated by the air blast from the aircraft. If the soil is very loose and unconsolidated, the rotor downwash or the propwash will not only kick up a cloud of dust, but larger soil particles will also be picked up and carried into the area about the aircraft. These particles are very abrasive and can be ingested into the engine, causing severe damage to the internal mechanism. Frequently, these particles can even obtain velocities that will damage the aircraft skin and canopies, or cause injury to personnel in the area.

If the native soils are small in particle size, the dust clouds create other tactical problems. These dust clouds are visible for many miles, and may persist for as long as an hour if there is no breeze to blow them away. Not only is enemy detection of operations enhanced, but lack of visibility will create interference with the utilization of the landing area for continued operations.

Several methods of soil stabilization can be employed to cope with the dust problem in the theater of operations. Permanent landing pads can be constructed which cover a large area and effectively eliminate the dust cloud. However, in limited war environments, the use of the customary construction materials such as concrete, asphalt, macadam, etc., is restricted for various reasons. Available manpower, specialized heavy equipment, and considerable time are required to construct the permanent pad. In addition, the above techniques require utilization of high density materials usually not indigenous to the area, thereby complicating the logistics problems.

Various types of membranes and metal landing mats have been utilized for soil stabilization. Here the problems are still the need for available manpower to install the landing aid. In the case of the membranes, the dust is still a big problem, because in most installations the membrane is not wide enough to effectively combat the dust outside the covered area. It is not practical to use metal mats for dust control.

Therefore, there exists a pressing need for a simple process involving an additive that can be used on native soils, possibly diluted with indigenous water, and applied with available equipment to produce an effective and reliable dust palliative. The objective of this program is to provide such an additive.

PART III: PRODUCT GUIDE LINES

The problem has been prevalent for a number of years, however, it has been most acute during the recent past because of military operations in southeast Asia. The U. S. Army Engineer Waterways Experiment Station at Vicksburg has been given the mission of finding a solution to this problem. Tentative requirements were established by the U. S. Army for a material which is to be used as a dust control agent and which provide guide lines for material research and development. These requirements are as follows:

1. Compatible for use in conjunction with aircraft, vehicles, troops and local population (non-corrosive, non-toxic).

2. Effective when applied at a rate of not more than three pounds per square yard.

3. Available in quantities sufficient to treat 5,000,000 square yards at a cost not to exceed $2.00 per square yard including cost of material and placement equipment.

4. Capable of being applied by engineer troops at a minimum rate of 500 square yards per man-hour.

5. Effective and operationally acceptable not more than four hours after placement.

6. Capable of being placed under temperatures ranging from 40° to 120°F, maximum humidity of 100 percent.

7. Capable of being effective when applied to all major soil types (sands, silts, clays) without extensive prior surface grading and/or other preconditioning.

8. Effective, with only minor hand maintenance, for a minimum period of six months.

9. Capable of withstanding occasional traffic from ground vehicles, helicopters and light cargo aircraft.

10. Capable of open storage under humid-tropical conditions for not less than three years.

In an effort to meet these requirements, The Western Company has taken a base material, which already met most of the requirements, and adapted it for use as a dust control agent. The material selected was a special plasticized blend of polyvinyl resins which has been used for other applications. The properties of the vinyl system appeared to fit most of the desired requirements before modification.

It appears that such a system can be sprayed on the surface of a soil, cure within the desired time limit, and form a tough resilient membrane for the control of dust.

PART IV: EXPERIMENTAL PROGRAM

The laboratory phase of this program consisted of blending appropriate materials and evaluating the resultant product. In addition to the original base materials, similar polyvinyl resins from various manufacturers were screened. Preliminary tests were conducted in small "potato boats" to observe the filming properties of the different products. (The "potato boats" were 5 inches by 3 inches oval aluminum dishes designed to hold baking potatoes. They were useful as disposable laboratory containers.) Those products which were obviously unsuitable were not evaluated further in the test program.

Laboratory evaluation was conducted according to "Memorandum for Record WESSS-3" as revised 17 March 1966, entitled "Laboratory Procedures and Tests for Screening of Proposed Dust-Control Materials." The tests were performed on soils having the following properties.

	Heavy Clay	Lean Clay	Fine Sand
Liquid Limit	53.1%	38.0%	
Plasticity Index	26.6%	14.2%	
% Passing 40 mesh sieve	100.0%	100.0%	100.0%
% Passing 200 mesh sieve	52.8%	54.9%	0.1%
Moisture Content	7.6%	1.8%	

These soils were compacted into molds measuring six inches by six inches and three inches deep. Following soil preparation in the mold, the samples of dust-control additive were applied to the soil. One type of sprayer used was a small aerating paint sprayer. Another spray system used an airless system with a nozzle to give a fan shaped discharge.

Some of the samples were simply measured and poured on the surface. They were then mechanically spread to achieve a coverage of the mold.

The treatment level was varied slightly depending on the viscosity of the materials. Most were applied at a calculated and measured rate of three pounds per square yard. Some of the samples were diluted with water and then added in greater volume, but always keeping the total concentration of additive below the three pound per square yard level.

The samples were allowed to cure at ambient laboratory conditions for a period not exceeding four hours. Following this curing period the samples were placed immediately into the air impingement test.

The air impingement apparatus was constructed from a Sutorbilt blower, powered by a two horsepower electric motor. The nozzle was shaped from three inch stainless steel tube stock. The nozzle was positioned so as to impinge the air stream at an angle of 20° from the

horizontal. With the attachment of appropriate hoses, the blower delivered the desired wind velocities at the surface of the samples. The desired wind velocities of 50 mph, 100 mph and 150 mph were controlled by a special valve which split the airstream and bled away portions of the air flow.

The rainfall tests were conducted in a chamber consisting of a tank suspended above a slowly rotating platform. The bottom of the tank was equipped with shower nozzles and a device to maintain a six inch head of water pressure during testing. The rotating platform was designed so the surface of the samples which were placed on it would be approximately ten inches below the shower nozzles. Then by adjusting the shower pattern, the samples revolving in the shower would not be subject to a constant impingement of water on any one surface location.

Small scale pilot plot tests were performed outside the laboratory. Soil samples were placed in one square yard wooden frames and sprayed with chemical additives. These tests gave better indications of how the additives would perform on large scale plots.

When the best formulations were determined, the materials were tested on larger scale pilot plots. Four plots were prepared. Three plots were located on a small, single lane roadway. The surface was subject to occasional traffic. The second plot was on an area of naturally compacted sandy loam. All vegetation had been removed to provide a firebreak in the grassland enclosure. Part of this plot was spaded and the soil turned over to produce a loose aerated soil approximately six to eight inches deep.

The dust palliatives were applied to these areas with an airless sprayer and allowed to cure for a period of four hours. At the end of the cure time an automobile and a small truck were driven over the plots. The surfaces were then inspected for cracks or failures in the coating. These plots were inspected periodically to determine aging and weather effects.

PART V: EXPERIMENTAL RESULTS AND DISCUSSION

A. Materials Development and Laboratory Testing

As this program was originally conceived, a film-forming additive prepared from a blend of polyvinyl resins was envisioned as providing a "sprayed-in-place" membrane for dust control. Therefore the first requirement was the formation of a film upon curing. The early screening tests used "potato boats" as containers for sand and clay samples. These soil samples were coated with each selected chemical to obtain a quick, qualitative film evaluation.

In addition to the original polyvinyl acetate base materials, many other resin emulsion materials were screened. Table I lists the materials screened and the observations made from the "potato boat" tests. Those products which were obviously unsuitable were not evaluated by the WESSS-3 standard procedures.

Many of the materials selected from the above screening appeared to have certain desired properties for film forming. These materials were then mixed with additives chosen to improve the individual product. Table II lists the materials which were tested as additives for the emulsion system. The reasons for selecting the additive as well as the test results are also recorded in Table II.

As the above tests were observed it became apparent that two of the emulsion bases, 972-D and 972-L, which were originally developed by The Western Company, were the better materials to optimize. Table III shows the results of varying the concentrations of the two base materials to select the best ratio. From these tests a 50-50 mixture of Base 972-D and Base 972-L was selected. This combination has been designated as HK-1.

Another similar system has been chosen and designated as HK-2. This is a 75-25 blend of Base 972-D and Base 972-L.

These products are terpolymers containing blends of polyvinyl acetates, polyvinyl acrylates and plasticizers in an emulsion system. For better all around application, these products contain both internal plasticizers and external plasticizers. That is, the internal plasticizer is a result of co-polymerization placing the plasticizer in the polymer chain. The external plasticizer is a flexibilizing agent not chemically bonded to the polymer chain which can be adjusted to control film properties at different temperatures.

Although HK-1 and HK-2 are very similar in composition, HK-2 appears to be the better product. The cured film is a little more flexible and a little more water resistant. Therefore most of the final testing was performed with HK-2 in order to determine more closely the material properties and how they would affect final application for dust control.

Table I

Materials Screened for Dust Control Agent

Material	Acceptable	Comments
Western Company		
Base 972-A	No	Product too viscous, film cracks on curing. Does not cure in 4 hrs.
Base 972-B	Maybe	Product too viscous - good film
Base 972-C	No	Product too viscous
Base 972-D	Yes	Appears good
Base 972-L	No	Film is firm, but brittle
Base DPE	No	Film softens in water
Base 792-E	No	Too viscous
Bordens Chemical Co.		
Polyco 505	No	Too viscous, film cracked, drying greater than 4 hrs.
Polyco 1361-4B	No	Weak film,viscous solution
Polyco 2415	No	Much cracking of film, slow cure
Polyco 446-1	No	No freeze - thaw stability
Polyco 561	No	Very brittle film, no water resistance
Polyco 8040L	No	
Polyco 678W	No	Film soft and shrinks
Lemac 40	Yes	Uses an acetone solvent base
Lemac 40	No	Alcohol solvent does not dry
Polyco 577G	No	No film strength
Polyco 1404-30	No	Poor film strength
Union Carbide Co.		
Ucar 360	Maybe	Firm surface - film brittle
Ucar 684	No	Excessive cracking
Ucar 130	Yes	Film appears good
Ucar 680	No	Unacceptable
Paper Binder 40	No	Film was tacky when cured
Dewey & Almy		
Everflex G	No	Slow cure
Everflex EF-61L	No	Brittle film
Everflex EF-E	No	Film too soft
Everflex EF-MF	No	Film too soft
Base 972-D + polystyrene in benzene	No	Product too viscous - film cracks
Base 972-D + 972-L 360	Yes	Film appears good
Base DPE + Ucar 360	No	Film was weak and cracks
Base 972-D + Polyco 446-1	No	No freeze - thaw stability
Base 972-D + 972-B	No	Product too viscous - hard to apply

Table I (cont.)

Materials Screened for Dust Control Agent

Material	Acceptable	Comments
10% styrene/benzene in 90% PVA/acetone	No	Very little strength
Base 972-D + Rexbond E-12 (Emkay)	No	Product too viscous
Base 972-D + Ucar 630	No	Film shows excessive cracking
Base 792-B + Ucar 360	No	Product too viscous
Base 792-B + Ucar 360 + 10% water	No	Film shrinks and cracks
15% PVA in 1:1 alcohol acetone	No	Not cured in 4 hrs.
15% PVA in acetone	Yes	
25% PVA in acetone	No	Too viscous, slow curing
Polyco 1361-4B + Polyco 446L	No	Film shrinks

Table II

Additives for Dust Control Agents

Additive	Base Material	Purpose	Results
Polystyrene in benzene	Base 972-D	Flexibilizing agent	Film cracked
10% D-1	HK-1	Improve penetration	Sample cracked before cure
1% Ethylene Glycol	HK-1	Improve freeze-thaw	Good film, improved flex at lower temps.
2.5% Ethylene Glycol	HK-1	Improve freeze-thaw	Some shrinkage of film
5% Ethylene Glycol	HK-1	Improve freeze-thaw	Some shrinkage of film, too soft
10% Dibutyl phthalate	HK-1	Plasticizer	Film too soft at room temp.
1% Dibutyl phthalate	HK-1	Plasticizer	Good
1% Ethylene Glycol	Polyco 446-L	Improve freeze-thaw	No benefit
5% Ethylene Glycol	Polyco 446-L	Improve freeze-thaw	No benefit
6% Dibutyl phthalate	Base 972-A	Plasticizer	Film too soft, shrinks
10% Dibutyl phthalate	Base 972-B	Plasticizer	Film too soft, shrinks
10% Dibutyl phthalate	Base 972-C	Plasticizer	Film too soft, shrinks
2% toluene	Base 972-D	Improve drying time	No help, increases viscosity
Portland Cement	HK-1	Filler	Enhanced film cracking
Silica flour	HK-1	Filler	Good, no cracking
Ethyl silicate	HK-1	Filler	Fair, some cracking
.75% Dibutyl phthalate	Base 972-B	Plasticizer	Brittle, cracks
5% Dibutyl phthalate	Base 972-B Base 972-D	Plasticizer	Film too soft

Table II (cont.)

Additives for Dust Control Agents

Additive	Base Material	Purpose	Results
1% Ethyl silicate	HK-1	Attractor for clay and silicates	Good firm film
5% Ethyl silicate	HK-1	Attractor for clay and silicates	Film too soft
10% Ethyl silicate	HK-1	Attractor for clay and silicates	Film too soft
.25% Ethyl silicate	HK-1	Attractor for clay and silicates	Good surface film, but it showed shrinkage
10% Silica flour	HK-1	Filler	Good film
6% Silica flour	HK-1	Filler	Good film
6% Silica flour 6% Portland Cement	HK-1	Filler	Good thick film, very viscous product
10% Portland Cement + 10% Silica flour	HK-1	Filler	Material too viscous
10% Silica flour + 6% Portland Cement	HK-1	Filler	Observed some shrinkage
20% Silica flour	HK-1	Filler	Film not as good as 6%
1% Ethyl silicate	HK-1	Filler	No change
5% Ethyl silicate + HCl	HK-1	Filler	No change
10% Ethyl silicate + HCl	HK-1	Filler	No change
0.1% sodium silicate	HK-1	Filler	Good film
0.5% sodium silicate	HK-1	Filler	Good film

Table II (cont.)

Additives for Dust Control Agents

Additive	Base Material	Purpose	Results
1.0% sodium silicate	HK-1	Filler	Film is brittle
0.1% sodium silicate + HCl	HK-1	Filler	Film is brittle
0.5% sodium silicate + HCl	HK-1	Filler	Film is brittle
1.0% sodium silicate + HCl	HK-1	Filler	Film is brittle
1-3% Teflon	HK-1	Filler	No observed changes
5%, 10%, 20% calcium carbonate	HK-1	Filler	Shrinkage of film
DAP (caulking compound)	HK-1	Filler	Would not cure
1% sand	HK-1	Filler	No change in film
5% sand	HK-1	Filler	Good film
1% clay	HK-1	Filler	No change in film
5% clay	HK-1	Filler	Good film
Sodium chloride	HK-1	Filler	No effect
Fiberglass	HK-1	Filler	Good film

Table III

Comparison of Concentration Variations of Mixtures Base 972-D and 972-L

Percent Base 972-D	Percent Base 972-L	Percent H_2O	Temperature ^0F	Film Properties on Soil: Lean Clay	Film Properties on Soil: Sand
50	50	-	95	SE	Wb
40	40	20	95	C	Wb
35	35	30	95	CC	Wb
30	30	40	95	CC	Wb
25	25	50	95	WCC	Nd
75	25	-	95	VSE	Wb
25	75	-	95	SC	Wb
87	13	-	95	VSE	Wb

S = Strong film
VS = Very strong film
E = Elastic film
W = Weak film
C = Cracking of the cured film
CC = Severe film cracking
b = Brittle film
Nd = Film did not cure

Wetting agents and flocculating agents were tested to determine if the materials would help produce a more even film, or condition the soil for better binding of the particles. Samples of oven-dried heavy clay were loosely packed into graduated cylinders and a standard volume of surfactant treated water was added. The rate and depth of penetration was measured. The results of these tests are recorded in Table IV.

The better wetting agents were selected from the above tests. Further tests were conducted with HK-1 to determine the effect of the wetting and penetrating agents on the film properties. These tests used the small "potato boat" samples for screening purposes. Soil samples (heavy clay) were placed in the container and sprayed lightly with treated water. Immediately thereafter the soil was coated with HK-1 and allowed to cure. Table V tabulates the results of these tests.

Laboratory results indicate that pre-wetting is necessary only when additives are sprayed on loose clays or perhaps on some loose silts. The very fine soil particles in a loose clay adhere to the surface of liquid droplets. The resultant high surface tensions of the liquids tend to prevent spreadage of the liquid body over the surface. If the loose clay is lightly sprayed with water before most filming agents are applied, the agent then covers or coats the clay a little more evenly. A small amount of wetting agent improves this even more.

HK-1 and HK-2 contain surface active agents as part of the composition in preparing the emulsion. When these materials are sprayed on loose clay, it is not necessary to pre-wet the soil. In fact, laboratory tests indicated that pre-wetting of the clays was often detrimental. That is, the clay tends to crack and shrink under the film as it is curing. If the cracking and shrinking occur during a certain portion of the curing cycle, the film parts leaving a crack of uncoated soil. Because of cracking and shrinking of the clays, it was found more desirable to use both HK-1 and HK-2 undiluted.

However, due to the viscosity of the solutions, they have to be diluted with water to be sprayable with existing road building equipment. HK-1 and HK-2 are prepared from non-ionic ingredients and can be diluted or mixed with water from almost any source -- fresh water, sea water, etc. Dilution ratios of one to one have been used in testing. Further dilution can be made and still produce integral films, but drying and curing times are extended beyond the desired four hour limitation and the cracking of loose clays becomes more pronounced.

The concentration of active ingredients in HK-2 is approximately 56% solids. Using current technology, this is as concentrated a solution as can be readily prepared with these ingredients.

After HK-1 and HK-2 were selected, they were evaluated according to the standard procedure. Both successfully passed the air impingement

Table IV

Wetting Agents and Flocculating Agents
For Soil Treatment

Agent	Percent	Base Fluid	Results
None	-	H_2O	3 ml penetration in 45 sec.
[1] D-1	16	H_2O	Improved spreading of d.p.
D-1	1	H_2O	5 ml penetration in 29 sec.
[2] Serfonic N-95	1	H_2O	5 ml penetration in 14 sec.
[3] Tergitol NPX	1	H_2O	5 ml penetration in 25 sec.
[1] D-1	5	H_2O	4 ml penetration in 25 sec.
[1] D-1	10	H_2O	3.5 ml penetration in 15 sec.
[1] D-1	15	H_2O	4 ml penetration in 25 sec.
[2] Serfonic N-95	5	H_2O	3 ml penetration in 45 sec.
[2] Serfonic N-95	10	H_2O	1 ml penetration in 60 sec.
[2] Serfonic N-95	15	H_2O	0.75 ml penetration in 120 sec.
[4] Arquad C	1	H_2O	3 ml penetration in 15 sec.
[4] Arquad C	5	H_2O	3 ml penetration in 27 sec.
[4] Arquad C	10	H_2O	3 ml penetration in 30 sec.
[4] Arquad C	15	H_2O	3 ml penetration in 40 sec.
[4] Arquad 12	1	H_2O	3 ml penetration in 31 sec.
[4] Arquad 12	5	H_2O	3 ml penetration in 45 sec.
[4] Arquad 12	10	H_2O	3 ml penetration in 55 sec.
[4] Arquad 12	15	H_2O	3 ml penetration in 60 sec.
[4] Arquad 16	1	H_2O	3 ml penetration in 40 sec.
[4] Arquad 16	5	H_2O	3 ml penetration in 46 sec.
[4] Arquad 16	10	H_2O	3 ml penetration in 60 sec.
[4] Arquad 16	15	H_2O	3 ml penetration in 60 sec.

Table IV (cont.)

Wetting Agents and Flocculating Agents
For Soil Treatment

Agent	Percent	Base Fluid	Results
KCl	1	H_2O	3 ml penetration in 15 sec.
KCl	2	H_2O	3 ml penetration in 45 sec.
KCl	5	H_2O	3 ml penetration in 30 sec.

Chemical Suppliers

[1] The Western Company
[2] Jefferson Chemical Co.
[3] Union Carbide
[4] Armour Industrial Chemicals Division

Table V

Prewetting of Clay Before Application of HK-1

Agent	Percent Additive	Volume of Water Per 6 sq. in. of Surface Area	Results
*D-1	16	3 ml	E(SCB)
D-1	16	4 ml	E(SCB)
D-1	16	5 ml	E(SCB)
$CaCl_2$	2	3 ml	E(SCA)
$CaCl_2$		4 ml	E
$CaCl_2$	2	5 ml	E
**Alconox and NaCl	5 & 10	3 ml	E
Alconox and NaCl	5 & 10	4 ml	E
Alconox NaCl	5 & 10	5 ml	E
*WW-1	1	3 ml	E(SCB)
WW-1	1	4 ml	E(SCB)
WW-1	1	5 ml	E(SCB)

E - elastic
SCB - slight cracking of clay before applying film
SCA - slight cracking of clay after applying film

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*The Western Company
**Alconox, Inc.

tests following the four hour curing time, and again following the one hour rainfall test. Results are recorded in Table VI. The samples as tested on the loose and compacted clays were very consistent in their performance. HK-1 and HK-2 are not consistent in their performance when tested on the loose sand. That is at the end of four hours cure on the loose sand, the film cures well enough to withstand the first air impingement test. However, the rainfall weakens the incompletely cured film and frequently the second air impingement test fails. Further testing indicated that these additives, HK-1 and HK-2, would successfully pass the entire series of standard tests on loose sand if they were allowed to cure at least seven hours before the rainfall test.

Considering film performance on the soil, some viscosity is beneficial -- especially on loose sand. If the additive is non-viscous and penetrates the sand before it cures, it has a tendency to act only as an adhesive between the sand grains and an integral film is not produced. This deeper penetration into the loose sand also produces longer curing times. By the nature of the particle adhesion, the surface created is rigid and non-flexible to random traffic. Therefore the surface fails under vehicle loads. Low viscosity can contribute to these undesirable properties.

Increased viscosity tends to keep the additive from penetrating, thereby producing an integral film across the surface. This film is then flexible and can deform under the stress of random traffic. However, on silts and clays, loose or compacted, the added viscosity is not necessary.

The viscosity or rheology results, which were previously described, indicate the role viscosity can play in the film forming properties. The other aspect of viscosity involves the application of the material to the soil. HK-2 has a Brookfield viscosity of 670 centipoise (10 rpm - # 1 spindle). This viscosity is too great to be sprayed with most existing road building equipment. Therefore, increasing the viscosity with viscosity builders is not desirable from the standpoint of material application.

Since viscosity increase did not appear to solve the application of additive to loose sand, several materials were tested as "fillers." It was reasoned that certain inert solids could be added to HK-1 and HK-2 which would bridge the void spaces between the sand grains. Then the resin emulsion could film the surface with a flexible layer. Table VII shows the results of these tests. The fillers were beneficial for the loose sand situation.

After HK-1 and HK-2 were selected, tests were performed to determine the setting or curing times at different temperatures between 40°F and 120°F. Table VIII lists these results plus comments on the film condition at each temperature.

Table VI

Rain and Air Impingement Tests on Non-Compacted Soils

Sample	Soil Type	1st Air Impingement	Rain	2nd Air Impingement	3rd Air Impingement
HK-1	CH	P	P	rippled	P
HK-1	CL	P	P	rippled	P
HK-2	CH	P	P	rippled	P
HK-2	CL	P	P	rippled	P
HK-3	S	P	P	P	P
HK-1 + 6% Silica Flour and Fiberglass	S	P	P	P	P

P = Passed test
CH = Heavy clay
CL = Lean clay
S = Sand

Procedure:

Samples prepared and allowed to dry 4 hours.

Air impingement test then applied wind velocities of 50, 100 and 150 mph.

The samples were then rained on for 1 hour.

At the end of this time the samples were again subjected to the air impingement test of 50, 100, 150 mph winds.

The samples were then allowed to dry at room temperature for 16 hours followed by 1 hour at 120°F.

The samples were again subjected to the impingement test.

Table VII

Fillers as Additives for HK-1

Filler Material	Percent Concentration	Results
Portland cement	1	G
Portland cement	2-6	CS
Silica flour	6	VG
Silica flour	10	G
Silica flour	20	G
Silica flour	6	CS
Portland cement	6	
Silica flour	10	CS
Portland cement	6	
Fiberglass	5	G
Silica flour	3	VG works well on sand
Fiberglass	3	
Silica flour	7.5	G viscous product
Fiberglass	7.5	
Portland cement + 2% Toluene	1	C
Portland cement + 2% Toluene	2	C
Portland cement + 2% Toluene	3	C
Portland cement + 2% Toluene	4	C
Calcium carbonate	5	C
$Ca(CO_3)_2$	5, 10, 20	All samples exhibited shrinkage

G = Good sample
VG = Very good sample
S = Strong
C = Cracked

Table VIII

Effects of Temperature on Setting Time and Film Properties

Material	Temperature ^0F									
	40^0	50^0	60^0	70^0	80^0	85^0	95^0	100^0	105^0	120^0
HK-1	Dry in 75 hrs. Film brittle and cracked	Dry in 4 hrs. Some film shrink-age	Dry in 4 hrs. Some shrink-age	Dry in 4 hrs. Film ply-able	Dry in 4 hrs. Film ply-able	Dry in 4 hrs. Good film	Dry in 4 hrs. Good film	Dry in 4 hrs. Good film	Dry in 4 hrs. Good film	Dry in 4 hrs. Good film
HK-2	Dry in 75 hrs. Film brittle and cracked	Dry in 4 hrs. Some film shrink-age	Dry in 4 hrs. Good film	Dry in 4 hrs. Good film	Dry in 4 hrs. Film ply-able	Dry in 4 hrs. Good film	Dry in 4 hrs. Good ply-able film	Dry in 4 hrs. Good ply-able film	Dry in 4 hrs. Good ply-able film	Dry in 4 hrs. Good ply-able film
HK-1 + 6% Silica flour and Fiber-glass	Dry in 75 hrs. Film brittle and cracked	Dry in 4 hrs. Some film shrink-age	Dry in 4 hrs. Some film shrink-age	Dry in 4 hrs. Good film						
HK-2 + 6% Silica flour and Fiber-glass	Dry in 75 hrs. Film brittle and cracked	Dry in 4 hrs. Some film shrink-age	Dry in 4 hrs. Some film shrink-age	Dry in 4 hrs. Good film						

HK-2 does not cure within the four-hour requirements at temperature below 60°F. When it does cure, the film is brittle and fractures easily. By adding approximately 5% of an additional external plasticizer, application at temperatures below 60°F can be performed. Under ideal conditions, it would be desirable for the product to normally contain the additional plasticizer. However, the film properties change when the plasticized film is heated to temperatures around 120°F. The film softens, and even though it would provide dust control, random traffic from heavy vehicles would most likely be detrimental. A plasticizer for all temperature ranges has not been found.

Table IX lists the materials tested as plasticizers for this emulsion system.

HK-1 and HK-2 were subjected to a freeze-thaw test to determine storage stability data. This test involved storing a sample at 0°F for 24 hours and then setting the sample at ambient room temperature (72°F) for 24 hours. This cycle was repeated seven times with HK-1 and HK-2 without detrimental results. No settling nor separation of solids from the sample was observed. Table X shows freeze-thaw test results.

Following the tests in which HK-1 and HK-2 failed to perform as desired on loose sand, another approach was investigated. A pure polyvinyl acetate (Borden's Lemac 40) was tested in several organic solvent systems. Most of these organic solvents did evaporate very rapidly to leave a good flexible film. However, the solvents which worked best were somewhat objectionable because of the fire hazard and the low flash points. It was reasoned that this problem could be tolerated if the product had exceptional properties. Table XI tabulates the solvents used for these tests.

A mixture of polyvinyl acetate in acetone solvent has been designated as HK-3. The acetone solvent allowed the film to cure much faster than the water based materials. HK-3 does pass all of the tests on loose sand at the end of four hours. In fact, it will pass the test in less than two hours under most curing conditions. Even though the product works well on loose sand, it appears to have limited application to other soil types. Because of the limited performance and the low flash point, HK-3 was not pilot plot tested later in this program.

B. Pilot Plot Tests

1. First Test Series (Small Scale Pilot Tests)

Small scale pilot tests were conducted by constructing wood frames from two-inch by four-inch planks which enclosed an area of one square yard. This frame was then filled with the desired soil and sprayed with one of the dust palliative additives.

Table IX

Screening of Potential External Plasticizers

Base Material	Plasticizer	Percent Concentration	Temperature ^0F	Results
HK-2	Ethylene glycol	1	60	Very good film - 2 small cracks in the surface.
HK-2	A-186*	1	60	Very good film
HK-2	Dioctyl adipate	1	60	Severe cracking of the film. Film very brittle .
HK-2	Dibutyl phthalate	1	60	Very good film.
HK-2	Ethylene glycol	1	40	Very poor. Film brittle and severely cracked.
HK-2	A-186	1	40	Very poor. Film brittle and severely cracked.
HK-2	Dioctyl adipate	1	40	Very poor. Film brittle and severely cracked.
HK-2	Dibutyl phthalate	1	40	Very poor. Film brittle and severely cracked.
HK-2	Ethylene glycol	1	50	Film had several small cracks. It was also brittle and weak.
HK-2	A-186	1	50	Film had several small cracks. It was also brittle and weak.
HK-2	Dioctyl adipate	1	50	Film had several small cracks. It was also brittle and weak.
HK-2	Dibutyl phthalate	1	50	Film had several small cracks. It was also brittle and weak.
HK-2	Dibutyl phthalate	5	40	Film displayed no cracks. Was slightly brittle in one corner. Good film.

Table IX (cont.)

Screening of Potential External Plasticizers

Base Material	Plasticizer	Percent Concentration	Temperature °F	Results
HK-2	A-186	5	40	Very good sample. Surface film was strong and elastic.
HK-2	Ethylene glycol	5	40	Film was weak and brittle
HK-2	Dioctyl adipate	5	40	Surface was very weak and brittle. Badly cracked.
HK-2	Dibutyl phthalate	5	60	Very good sample, no cracks, good strong surface film
HK-2	A-186	5	60	Several small cracks, film brittle
HK-2	Ethylene glycol	5	60	Film badly cracked and very brittle
HK-2	Dioctyl adipate	5	60	Film cracked and brittle

*beta - 3, 4 (epoxycyclohexyl) ethyltrimethoxy silane

Table X

Freeze-Thaw Stability Tests

Sample	Cycles 1	2	3	4	5	6	7
Base 972-A	g	g	x	-	-	-	-
Base 972-A + ethylene glycol	✓	✓	s	s	s	✓	✓
Base 972-B	✓	✓	s	✓	✓	✓	✓
Base 972-B + ethylene glycol	✓	✓	s	✓	✓	✓	✓
Base 972-C	g	g	x	-	-	-	-
Base 972-C + ethylene glycol	g	g	x	-	-	-	-
Polyco 1404-30	✓	✓	✓	✓	✓	✓	✓
Polyco 1404-30 + ethylene glycol	✓	✓	✓	✓	✓	✓	✓
Polyco 505	x	x	-	-	-	-	-
Polyco 505 + ethylene glycol	x	x	-	-	-	-	-
0153	g	g	x	-	-	-	-
0153 + ethylene glycol	✓	✓	s	s	s	s	s
Polyco 1361-4B	✓	✓	✓	✓	✓	✓	✓
Polyco 1361-4B + ethylene glycol	✓	✓	✓	✓	✓	✓	✓
Polyco 446L	x	x	-	-	-	-	-
Polyco 446L + ethylene glycol	x	x	-	-	-	-	-
Ucar 360	✓	✓	✓	✓	g	s	g
Ucar 360 + ethylene glycol	✓	✓	✓	✓	✓	✓	✓
Polyco 522	x	x	-	-	-	-	-
Polyco 522 + ethylene glycol	x	x	-	-	-	-	-
Base 972-D	x	x	-	-	-	-	-
Base 972-D + ethylene glycol	✓	✓	✓	✓	✓	✓	✓
HK-1	✓	✓	✓	✓	✓	✓	✓
HK-2	✓	✓	✓	✓	✓	✓	✓

x - emulsion broke
✓ - sample O.K.
g - sample grainy
s - required stirring

Table X (cont)

Samples were prepared with each material to be tested for freeze-thaw.

Each material was put in a polyethylene bottle and frozen for 24 hours, defrosted for 24 hours and refrozen. This was repeated seven times. At the end of this time, samples were again prepared.

Table XI

Solvents for Polyvinyl Acetate +

Solvent	Percent Lemac 40	Additives	Film Properties on Soil: Heavy Clay	Lean Clay	Sand	Drying Time
Ethyl Alcohol (3A)	12.5	None			S	> 4 hrs
Acetone	12.5	None	W		SE	
50% Acetone 50% Alcohol	15.0	None			VS	
25% Acetone 75% Alcohol	15.0	None	W		S	> 4 hrs
13% Acetone 87% Alcohol	15.0	None	WC		S	> 4 hrs
Acetone	25.0	None			S	> 4 hrs
50% Acetone 50% Isopropyl Alcohol	15.0	None			S	
Acetone	15.0	6% Silica Flour and Fiberglass	WC	WC	S	
Acetone	15.0	6% Silica Flour and Fiberglass 1% Wetting Agent A-186	WC	WC	S	
Acetone	15.0	6% Silica Flour and Fiberglass 5% Wetting Agent A-186	WC	WC	S	
Trichloroethylene	15.0	None			S	> 4 hrs

Table XI (cont.)

Solvents for Polyvinyl Acetate #

Solvent	Percent Lemac 40	Additives	Film Properties on Soil: Heavy Clay	Lean Clay	Sand	Drying Time
50% Acetone 50% Alcohol	15.0	5% Isobutyl Methocrylate	No Cure			>> 4 hrs

S = strong film
VS = very strong film
E = elastic film
W = weak film
C = cracks in cured film

Lemac 40 Borden's Chemical Co.

In Test 1 the plot was filled with uncompacted Texas gumbo clay, pre-wetted with a 2% calcium chloride solution, and sprayed with HK-1. At the end of four hours, drying and curing was incomplete. Certain low depressions contained "puddles" of uncured resin. The remainder of the film was flexible.

The plot for Test 2 was filled with construction sand. The area was sprayed with HK-1 and allowed to cure. Curing required longer than four hours, but the film was strong and firm when cured.

Both Test 1 and Test 2 were out in the weather for 12 days. Temperature variations ran from 60°F to 100°F. A period of rainfall was measured at 1.3 inches.

Test 3 and 4 were prepared by filling the test frames with uncompacted heavy clay and lean clay respectively. The soils were pre-wetted with a 2% calcium chloride solution before spraying with HK-1. After the films had cured, minor cracking of the clay was observed near the edge of the plot frames. Otherwise, the film was strong and flexible.

Plots were again prepared containing uncompacted heavy clay and lean clay. For Tests 5 and 6 the plots were sprayed with HK-2. After four hours some cracking of the lean clay was observed near the plot frames. However, each of the cracks was sealed by the HK-2 film.

The four tests described above were observed for a period of ten days. During this time the plots were subjected to 1.3 inches of rainfall. There was no visible evidence of damage to the film by the rain. Temperatures fluctuated between 60°F and 100°F during Tests 3 through 6.

Tests 7 and 8 were also prepared with heavy clay and lean clay. The soils were placed dry and loose and not pre-wet before spraying with HK-1. Observations indicated that the drying time was shortened and there was virtually no cracking of the soil. Temperatures during the test period ran 60°F to 100°F. The experimental dust control additives were subjected to a rainfall of 4.9 inches during the observation period of eight days. No detrimental results were observed.

2. Second Tests Series (Full Scale Pilot Tests)

Two different series of pilot plot tests were performed. The first test was conducted in September. The soil temperatures at night were warm (mid 70's) and the day time atmospheric temperatures ran in the 90's. The humidity was measured at 26% to 45%. Two plots were prepared and tested under these conditions.

Plot I was located on a small single lane roadway which carried occasional traffic to a test area. The soil under the plot was a well compacted lean clay. The plot was measured, marked and dust palliative applied with an airless sprayer. The average concentration of HK-2

additive across the plot was 2.2 pounds per square yard. The plot was allowed to dry and cure for four hours. At the end of this period the filmed surface was inspected and an additional coating was sprayed on one half of the plot at the concentration of 1.6 pounds per square yard.

Plot II was prepared on an area of naturally compacted sandy loam. This area had previously been scraped clean of vegetation to prepare a firebreak. One half of this plot was spaded and the soil aerated to a depth of six to eight inches. The entire plot was sprayed with a concentration of 2.8 pounds of HK-1 per square yard. At the end of three hours, one half of the plot (covering both compacted and aerated soil) was sprayed again with 1.6 pounds per square yard of the same additive.

Twenty-four hours later, the plots were observed for quality of the film coating. Plot I on the roadway had formed a very good film. All small rocks and soil particles were bound in place. The area which had been coated with two applications had a smoother film and appeared to have more strength. Multiple passes of an automobile over the plot did not show on the film. Even the area with one coat revealed no tire impressions.

This area was opened to the normal occasional traffic and inspected periodically. For two months the film held well. Then the roadway was used regularly by some moderately heavy truck traffic. One month later the surface was well cracked and showing signs of heavy wear. Strong wind velocities would have blown sections of the film away after the heavy traffic had broken up the surface.

Plot II also exhibited good film coverage. When an automobile was driven across this plot, the film on the compacted soil did not show impressions into the coating. However, when the car passed across the coating on the loose aerated soil, a deep rut was produced which was some three inches deep. The film stretched to conform to the deformation, and did not rupture. Even though the double coated area was obviously much stronger and supported the weight much better, the single coated area adequately covered the deformation without failure.

Plot II was subjected only to random traffic. As such, it did not have the wear as in Plot I. Seven months later the film coating was still adequate to provide dust control even under strong wind velocities.

3. Third Test Series (Full Scale Pilot Tests)

The second series of pilot plot tests were performed in late December in order to obtain low outdoor-soil temperatures. Two adjacent plots were prepared and sprayed with approximately 3.0 pounds of HK-2 per square yard. Both plots were located on the small single lane roadway. Soil temperatures at the time of spraying were between 45°F and 47°F.

Plot III was sprayed with HK-2. Plot IV was sprayed with HK-2 containing 5% by volume additional external plasticizer. The plots were allowed to cure for a period of four hours. At the end of this time, each plot was examined to evaluate properties. Both plots had dried to a tack-free surface. However, there was a definite difference in the flexibility of the films. The HK-2 with added plasticizer had much more resilience to it. When the coating, over soft soil, was indented with a blunt instrument, the film deformed to take the shape of the indentation. The film deformed, but did not fail.

On Plot III where the HK-2 did not contain added plasticizer, the same probing caused a small crack in the film after it was deformed. This plot also revealed small cracks in the surface after it was subjected to vehicle traffic.

These tests indicate that HK-2 without the added plasticizer was too brittle to pass trafficability tests at curing temperatures as low as 45^{0}F. The HK-2, adjusted with additional plasticizer, appeared to perform well.

PART VI: CONCLUSIONS

Of all the materials screened and tested, it appears that a mixture of two of the original base materials perform the best. That is, a blend of Western's polymer base D and polymer base L produce the desired results in a dust control additive. The addition of other wetting agents did not improve the ease of coverage or penetration. The surfactant which produces the emulsion is sufficient to cause good wetting of soils.

Fillers were an improvement only when used on loose sand. For this application it appeared that long strands of fiberglass sprayed with HK-2 had the best chance of meeting the requirements.

It is concluded that the following properties make HK-2 a usable dust control additive:

Composition

HK-2 is an emulsified, water phase, terpolymer blend of polyvinyl acetate, polyvinyl acrylates and internal plasticizers. This system is then further plasticized with an external plasticizer.

Physical Properties

Freeze-thaw -- HK-2 is uneffected after seven freeze-thaw cycles.

Viscosity -- 670 Brookfield centipoise at 10 rpm on # 1 spindle, 72°F.

Density -- 1.07 gms/cc at 70°F.

Surface film -- HK-2 dries and cures to form a tough resilient film. This film curing time is dependent upon temperature and humidity. The additives can be applied to soils without prior treatment. If the film is broken or ruptures under stress, it can be repaired by re-spraying the area with more of the additive. The surface film has been successfully subjected to wind velocities of 50 mph, 100 mph and 150 mph before and after one hour of rainfall; also 20 hours later after drying at 120°F for one hour.

Plasticizers -- HK-2 normally contains an internal and an external plasticizer. This gives a good, strong flexible film when applied at temperatures 65°F to 120°F. For temperatures 40-65°F an additional plasticizer (5% by volume Dibutylphthalate) must be added to control brittleness.

Dilution with water -- Dilution of HK-2 with water causes an increase in the drying time. On loose clays it also tends to cause cracking of the soil under the film.

Pre-wetting of soils -- HK-2 contains a surfactant which aids in wetting the soil. Therefore, pre-wetting is not a requirement. Testing indicated the pre-wetting of loose clays was an aid in some cases -- but not a requirement.

Curing time -- HK-2 will cure and dry in less than four hours at ambient temperatures and approximately 50% humidity when sprayed on lean or heavy clays. However, at least seven hours is required for curing on loose sand.

Spraying -- Spraying of the additive can be accomplished with an airless sprayer with pressures of 80-120 psi (depending on the nozzle size). Pumping with existing equipment (road sprayers) is difficult unless diluted with water.

Storage -- HK-2 should have good storage stability if the seals are unbroken. Regular steel drums are unsuitable unless lined with a coating such as baked phenolic resin, polyethylene, or other similiar lining. The water in the emulsion causes rusting of the container. The material can be stored at temperatures as low as 0°F.

PART VII: RECOMMENDATIONS

The Western Company recommends HK-2 for large scale testing to prove its merits as a dust control agent.

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13. ABSTRACT

This report describes the efforts to develop a soil stabilizing additive which would serve as an effective dust palliative in the theater of operations. In the initial phase of the testing program a large number of soil treatment candidates were screened. To accomplish this, small specimens were prepared and observed. The most satisfactory of these candidates were evaluated by the WESSS-3 standard procedures designated "Tests for Screening of Proposed Dust-Control Materials." Two candidates were selected on the basis of their good performance for small scale pilot tests. One square yard specimens were prepared over various types of uncompacted clay and sand and exposed to weathering. A single candidate was selected for further testing. Full scale pilot plot tests were conducted with the fully developed product over compacted clay and loam under both summer and winter conditions. All specimens were then submitted to trafficability tests. A soil treatment material has been recommended which is a terpolymer blend of polyvinyl acetate, polyvinyl acrylates and internal plasticizers.

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